(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 1 193 386 A2**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.04.2002 Bulletin 2002/14

(51) Int Cl.[7]: **F02D 41/38**, F02D 33/02, F02D 41/12

(21) Application number: **01000456.2**

(22) Date of filing: **13.09.2001**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **27.09.2000 US 671713**

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(54) **A method for reducing evaporative emissions during engine shutdown**

(57) A method of controlling an engine 12 during engine shutdown to reduce evaporative emissions is disclosed in which the method includes a step 50 of shutting off a fuel pump 28 of the engine 12 followed by the step 52 of burning off the fuel from a fuel rail 24 in a cylinder 18 of the engine 12 after the fuel pump 28 is shut off.

During the burning off of the fuel, a duty cycle of each fuel injector 22 of engine 12 is controlled to allow the engine 12 to operate generally cyclically about a predetermined air/fuel ratio which is preferably stoichiometric.

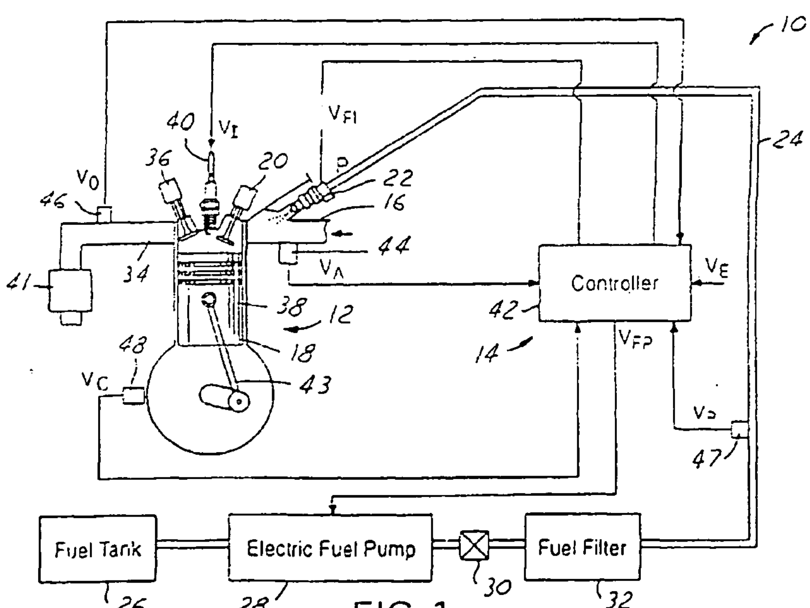

FIG. 1

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Description

[0001] This invention relates to a method for controlling an internal combustion engine during engine shutdown to reduce evaporative emissions and in particular relates to a method for reducing fuel pressure in a fuel rail of the engine during engine shutdown.

[0002] Internal combustion engines are generally controlled to maintain the ratio of air and fuel at or near stoichiometric. In particular, the engines are controlled utilizing closed-loop control where the amount of fuel delivered to the engine is determined primarily by the concentration of oxygen in the exhaust gases. The amount of oxygen in the exhaust gas is indicative of the ratio of air and fuel that has been ignited in the engine.

[0003] Known engines sense the oxygen level in the exhaust gases of the engine utilizing a Heated Exhaust Gas Oxygen (HEGO) sensor. Further, known engine control systems adjust the commanded air/fuel ratio of the engine responsive to the output of the HEGO sensor.

[0004] Known engines also utilize a three-way catalytic converter to reduce the unwanted by-products of combustion. The ratio of air and fuel may be maintained near stoichiometric for efficient operation of the catalytic converter.

[0005] Known engine control systems stop the closed-loop control of an engine when an ignition switch changes to a state that indicates that the engine should be shut down and immediately shut off a fuel pump and stop transmitting control signals to fuel injectors of the engine.

[0006] As a result, the fuel injectors immediately stop supplying fuel to the engine cylinders and leave any unused fuel in the fuel rail.

[0007] The term "fuel rail" means one or more fuel lines supplying fuel to one or more fuel injectors.

[0008] It has been determined that leaving the fuel in the fuel rail at a relatively high pressure, after engine shutdown, results in increased evaporative emissions.

[0009] It is an object of the invention provides an automotive vehicle and a method of controlling an internal combustion engine during engine shutdown to reduce evaporative emissions

[0010] According to a first aspect of the invention there is provided a method for depressurizing a fuel rail in an internal combustion engine during engine shutdown to reduce evaporative emissions, the engine having a fuel pump supplying fuel through the fuel rail to a fuel injector, the fuel injector communicating with an engine cylinder characterised in that the method comprises the steps of, shutting off the fuel pump and burning off the fuel in the fuel rail after the fuel pump is shut off.

[0011] During burning off of the fuel a duty cycle of the fuel injector may be controlled to allow the engine to operate generally cyclically about a predetermined air/fuel ratio.

[0012] Preferably, the predetermined air/fuel ratio may be a stoichiometric air/ fuel ratio.

[0013] The step of burning off the fuel may include, measuring an oxygen level in exhaust gases of the engine, controlling the duty cycle of the fuel injector responsive to the oxygen level and igniting the fuel from the fuel injector in the cylinder while the duty cycle of the fuel injector is being controlled.

[0014] The oxygen level may be measured in an exhaust manifold of the engine.

[0015] The controlling the duty cycle of the fuel injector may include the steps of, calculating a commanded air/fuel ratio responsive to the oxygen level, calculating a commanded fuelling level responsive to a measured intake manifold mass air flow and the commanded air/fuel ratio and selectively increasing the duty cycle of the fuel injector responsive to the commanded fuelling level, after the fuel pump is shut off, to allow the engine to operate cyclically about the predetermined air/fuel ratio.

[0016] When the oxygen level indicates a lean operating condition the duty cycle of the fuel injector may be increased.

[0017] The burning off of the fuel may be stopped responsive to an engine operational parameter and a threshold value.

[0018] The engine operational parameter may be the measured oxygen level in the exhaust gases of the engine and the threshold value is a threshold oxygen level, wherein the burning off of the fuel is stopped when the oxygen level is greater than the threshold oxygen level.

[0019] Alternatively, the engine operational parameter may be a measured or calculated fuel rail pressure in the engine and the threshold value is a threshold pressure level, wherein the burning off of the fuel is stopped when the measured or calculated fuel rail pressure is less than the threshold pressure.

[0020] As yet another alternative the engine operational parameter may be the duty cycle of the fuel injector and the threshold value is a threshold duty cycle, wherein the burning off of the fuel is stopped when the duty cycle of the fuel injector is greater than the threshold duty cycle.

[0021] According to a second aspect of the invention there is provided a method for controlling an internal combustion engine during engine shutdown to reduce evaporative emissions, the engine having a fuel pump supplying fuel through a fuel rail to a fuel injector, the fuel injector communicating with an engine cylinder, characterised in that the method includes using a method for depressurizing a fuel rail in an internal combustion engine according to the first aspect of this invention.

[0022] According to a third aspect of the invention there is provided a motor vehicle having an engine having a fuel injector selectively supplying fuel to a cylinder of the engine, the engine further including a fuel pump selectively supplying fuel through a fuel line to the fuel injector and a controller operatively connected to the fuel injector and the fuel pump characterised in that the controller is configured to shut off the fuel pump upon a change of state of an engine control signal and to control

a duty cycle of the fuel injector, after the fuel pump is shut off, to allow the engine to operate cyclically about a predetermined air/fuel level.

[0023] The vehicle may have an oxygen sensor operatively connected to the controller, the oxygen sensor generating a oxygen level signal indicative of a level of oxygen in exhaust gases of the engine, the controller varying the duty cycle of the fuel injector control signal responsive to the oxygen level signal.

[0024] The oxygen sensor may be a heated exhaust gas oxygen sensor.

[0025] When the oxygen level indicates a lean operating condition for increasing periods of time, the controller may be operational to increases the duty cycle of the fuel injector control signal.

[0026] The controller may be further configured to shut off the fuel injector responsive to an engine operational parameter and a threshold value.

[0027] According to a fourth aspect of the invention there is provided engine controller for an engine of the type having an intake manifold with a mass air flow sensor generating a mass air flow signal responsive to an amount of air flow in the intake manifold, an exhaust manifold with an oxygen sensor generating an oxygen level signal responsive to an amount of oxygen in exhaust gases in the exhaust manifold, and a fuel pump supplying fuel to a fuel injector, characterised in that the controller is configured and arranged to turn off the fuel pump upon a change of state of an engine control signal, the controller being further configured to calculate a commanded air/fuel ratio responsive to the oxygen level signal, the controller being further configured to calculate a commanded fuelling level responsive to the mass air flow signal and the commanded air/fuel ratio, the controller being further configured to control a duty cycle of the fuel injector, after the fuel pump is shut off, to allow the engine to operate cyclically about a predetermined air/fuel ratio.

[0028] The controller may be operational when the oxygen level indicates a lean operating condition for increasing periods of time to increase the duty cycle of the fuel injector.

[0029] The invention will now be described by way of example with reference to the accompanying drawing of which:-

Figure 1 is a combination schematic and block diagram of an automotive vehicle having an engine and a control system for implementing a method in accordance with the present invention;

Figures 2A-G are diagrams illustrating engine control signals and parameters in accordance with a known method of shutting down an engine;

Figures 3A-G are diagrams illustrating engine control signals and parameters in accordance with a method of shutting down an engine in accordance with the present invention;

Figures 4A-C are flow charts illustrating a method for controlling an engine during an engine shutdown time interval in accordance with the present invention;

Figure 4D is a decision chart in accordance with the invention.

[0030] Referring now to the drawings wherein like reference numerals are used to identify identical components in the various views, Figure 1 illustrates an automotive vehicle generally indicated by numeral 10. The vehicle 10 includes an internal combustion engine 12 and a control system 14.

[0031] The engine 12 comprises an internal combustion engine having an intake manifold 16, a number of cylinders 18, intake valves 20, fuel injectors 22, a fuel rail 24, a fuel tank 26, a fuel pump 28, a check valve 30, a fuel filter 32, an exhaust manifold 34, exhaust valves 36, pistons 38, spark plugs 40 and a catalytic converter 41.

[0032] Each of the cylinders 18 may have a corresponding fuel injector 22, intake valve 20, exhaust valve 36, and spark plug 40, for purposes of clarity only one cylinder 18 is shown in Figure 1.

[0033] It will be appreciated that the invention is also applicable to other fuel delivery systems such as a central fuel injected (CFI) system for each cylinder bank of an engine.

[0034] The intake manifold 16 directs air flow to the cylinders 18 of the engine 12. In particular, the manifold 16 directs air to an intake valve 20 which selectively controls the amount of air entering the respective cylinder 18. The configuration of the manifold 16 may vary based upon the number of cylinders 18 of the engine 12.

[0035] The fuel injectors 22 selectively provide fuel to one or more cylinders 18 and are conventional in the art. In particular, each fuel injector 18 delivers a predetermined amount of fuel into one or more cylinders 18 responsive to a fuel injector control signal VFI generated by the controller 42. Further, each fuel injector 28 receives a distinct fuel injector control signal VFI from the controller 42.

[0036] The controller 42 varies the duty cycle of each fuel injector control signal VFI during an engine shutdown time interval as will be described in further detail below.

[0037] The components of engine 12 providing fuel to the fuel injectors 22 will now be discussed. The fuel pump 28 delivers fuel from the fuel tank 26 through the check valve 30 and the fuel filter 32 into the fuel rail 24. The fuel rail 24 supplies the pressurized fuel to the fuel injectors 22. The fuel pump 28 may comprise an electric fuel pump or the like and is turned on or off responsive to a fuel pump control signal VFP generated by the controller 42. The check valve 30 is provided to maintain

fuel pressure in the fuel rail 24 when the fuel pump 28 is shut off.

[0038] In particular, the check valve 30 closes when the fuel pump 28 is turned off which maintains the fuel in the fuel rail 24 at a relatively high pressure. Generally, the fuel in the fuel rail 24 is maintained at the high pressure so that sufficient fuel is available at the fuel injectors 22 when starting the engine 12. However, as previously discussed, undesirable evaporative emissions result from leaving the fuel at the high pressure after engine shutdown.

[0039] The exhaust manifold 34 directs exhaust gases from the cylinders 18 to the catalytic converter 41. In particular, the exhaust manifold 34 communicates with exhaust valves 36 which selectively control the amount of exhaust gases entering the exhaust manifold 34. The configuration of the manifold 34 may vary based upon the number of cylinders 18 of the engine 12.

[0040] The spark plugs 40 are provided to ignite the fuel in the cylinders 18 to drive the pistons 38. Each spark plug 40 ignites fuel in a cylinder 18 responsive to an ignition control signal VI generated by the controller 42. The controller 42 may generate each ignition control signal VI responsive to a position of the crankshaft 43 as known by those skilled in the art.

[0041] The catalytic converter 41 is provided to reduce undesirable by-products of combustion in the engine 12, and is operatively connected to the exhaust manifold 34.

[0042] The control system 14 is provided to control the engine 12 during an engine shutdown time interval to reduce evaporative emissions in accordance with the present invention.

[0043] The control system 14 comprises a mass air flow sensor 44, an oxygen sensor 46, a fuel pressure sensor 47, a crankshaft position sensor 48, and a controller 42.

[0044] The mass air flow sensor 44 generates a signal VA indicative of the mass air flow in the intake manifold 16.

The controller 42 receives the signal VA and derives the measured value of mass air flow MAF from the signal VA. The sensor 44 is conventional in the art and is disposed in the intake manifold 16.

[0045] The oxygen sensor 46 generates a oxygen level signal VO proportional to the concentration of oxygen in the exhaust gases in the exhaust manifold 34. As previously discussed, the oxygen sensor 46 may comprise a Heated Exhaust Gas Oxygen (HEGO) sensor. The oxygen sensor 46 may comprise a hollow zirconium oxide (ZrO_2) shell, the inside of which is exposed to atmosphere. The controller 42 receives the oxygen level signal VO and calculates a measured oxygen level responsive to the oxygen level signal VO. The measured oxygen level is compared to a predetermined oxygen value which, for the particular oxygen sensor 46 used, represents the sensor voltage output for a stoichiometric air /fuel ratio.

[0046] This comparison produces a two-state condition flag indicating either a rich condition or a lean condition.

[0047] A rich condition occurs when the measured oxygen level is less than the predetermined oxygen level that is to say the air/fuel ratio is less than stoichiometric.

[0048] A lean condition occurs when the measured oxygen level is greater than the predetermined oxygen level that is to say the air/fuel ratio is greater than stoichiometric.

[0049] The fuel pressure sensor 47 generates a fuel pressure signal VP indicative of the fuel pressure in the fuel rail 24. The pressure sensor 47 is conventional in the art. The controller 42 receives the fuel pressure signal VP and derives the measured fuel rail pressure P responsive to the fuel pressure signal VP.

[0050] In an alternate embodiment (not shown), the fuel pressure sensor 47 is removed from the control system 14 and the fuel pressure P is calculated responsive to the rate of fuel flow through the fuel rail 24 as known by those skilled in the art.

[0051] The crankshaft position sensor 48 generates a crankshaft position signal VC indicative of the rotational position of the crankshaft 43. The crankshaft position sensor 48 is conventional in the art and may comprise a hall effect sensor. The controller 42 receives the crankshaft position signal VC and generates the ignition control signals VI responsive thereto, as known by those skilled in the art.

[0052] The controller 42 may further calculate the engine speed S responsive to the crankshaft position signal VC.

[0053] The controller 42 is provided to control the engine 12 in accordance with the present invention. The controller 42 is conventional in construction and is electrically connected to the fuel injectors 22, the fuel pump 28, the mass air flow sensor 44, the oxygen sensor 46, the spark plugs 40, and the crankshaft position sensor 48.

[0054] During engine operation, the controller 42 receives oxygen level signal VO and controls the commanded air/fuel ratio AF and thus the commanded fuelling level W responsive to the signal VO. For example, an oxygen level signal VO indicating a rich air/fuel ratio will result in an increase in the commanded air/fuel ratio AF and a corresponding decrease in the commanded fuelling level W to the engine 12. Alternately, an oxygen level signal VO indicating a lean air/fuel ratio will result in a decrease in the commanded air/fuel ratio AF and a corresponding increase in commanded fuelling level W to the engine 12.

[0055] The controller 42 includes a read-only memory (ROM) (not shown) that stores a software program for implementing the methods in accordance with the present invention.

[0056] The controller 42 also includes drivers (not shown) to transmit the respective control signals to the fuel injectors 22, the fuel pump 28, and the spark plugs

40.

[0057] Figures 2A-2G illustrate signals and parameters generated while implementing a known engine control method before and after engine shutdown. As will be shown, the control method results in a relatively high residual fuel pressure in the fuel rail 24 after engine shutdown. The high residual fuel pressure results in undesirable evaporative emissions from the fuel injectors 22. The engine 12 and the control system 14 may be utilized with the known engine control method and the inventive engine control method discussed in more detail below.

[0058] Referring to Figures 2A and 2B, during time interval T=0 to T=TO, the controller 42 receives an engine control signal VE with a high logic level---indicating that engine 12 should have closed-loop controlled operation. In particular, the engine control signal VE may be transmitted to the controller 42 from an ignition switch (not shown). For example, if an operator closes an ignition switch to start the engine 12, the engine control signal VE may transition from a low logic level to a high logic level. Conversely, if an operator opens an ignition switch to shut off the engine 12, the engine control signal VE may transition from a high logic level to a low logic level. Referring to Figure 2B, in response to the signal Ve, the controller 42 generates a fuel pump control signal VFP with a high logic level. In response to the signal VFP, the fuel pump 28 delivers fuel through the fuel rail 24 to the fuel injectors 22. Thus, the measured fuel rail pressure P (represented by Vp) is maintained at a relatively constant pressure as illustrated in Figure 2C.

[0059] Referring to Figures 2D and 2E, during time interval T=0 to T=TO, the oxygen level signal VO oscillates about a stoichiometric level as known by those skilled in the art. Further, the commanded air/fuel ratio AF oscillates about a corresponding stoichiometric level responsive to the oxygen level signal VO. In particular, when the oxygen level signal VO indicates the measured air/fuel ratio is stoichiometric, the commanded air/fuel ratio AF "jumps back" to a predetermined nominal air/fuel mixture which is hoped to be at or near stoichiometric. Thereafter, the commanded air/fuel ratio AF is gradually altered in a direction opposite to its prior direction of change until the oxygen sensor 46 determines that stoichiometry has again been reached.

[0060] Referring to Figures 2F and 2G, during time interval T=0 to T=TO, the average commanded fuelling level W is at a relatively constant value responsive to the commanded air/fuel ratio AF. Further, the average duty cycle of the fuel injectors 22 is at a relatively constant value responsive to the commanded fuelling level W.

[0061] Referring to Figure 2A, at time T=TO, the engine control signal VE transitions to a low logic level indicating that the engine 12 should be shut down. In response to the signal VE, the controller 42 immediately transitions the fuel pump control signal VFP to a low logic level to shut off the fuel pump 28.

[0062] Referring to Figures 2D and 2E, after time T=TO, the oxygen level signal VO remains at a constant value and the oscillation of the commanded air/fuel ratio AF is stopped. Referring to Figures 2F and 2G, the average commanded fuelling level W falls to a zero value and correspondingly the duty cycle of the fuel injector control signal VFI falls to a zero value. As illustrated in Figure 2C, the fuel pressure P (represented by pressure signal VP) in the fuel rail 24 remains at a relatively high pressure level because the check valve 30 closed when the fuel pump 28 turned off.

[0063] Although not shown in Figure 2C, the fuel rail pressure P may eventually decrease over time if the residual fuel in the fuel rail 24 migrates past the fuel injectors 22 into the intake manifold 16. Thus, the known engine control method may result in undesirable evaporative emissions from the fuel injectors 22.

[0064] The controller 42 operates in accordance with a software program stored in the ROM (not shown) which implements the method of controlling an internal combustion engine in accordance with the present invention. Figures 4A-4D form a flowchart of the inventive method that is implemented by the software program and the Figures 3A-3G illustrate the signals and parameters generated while implementing the inventive method.

[0065] Referring to Figure 4A, a method of controlling an internal combustion engine 12 includes a step 50 of shutting off the fuel pump 28 of the engine 12. Referring to Figures 3A and 3B, at time T0, the engine control signal VE, transitions to low logic level indicating that the engine 12 should be shut down. As previously discussed, the engine control signal VE may be controlled by an ignition switch (not shown).

[0066] Alternatively, the engine control signal VE may be a control value calculated responsive to the state of an ignition switch (not shown) of the engine 12.

[0067] The method further includes a step 52 that burns off fuel from the fuel rail 24 in one ore more cylinders 18 after the fuel pump 28 is shut off. During the burning of the fuel, a duty cycle of the fuel injectors 22 is controlled to allow the engine 12 to operate generally cyclically about a predetermined air/fuel ratio. The predetermined air/fuel ratio is preferably stoichiometric.

[0068] Referring to Figure 4B, the step 52 may include the substeps 54, 56, and 58. The substep 54 measures the oxygen level in the exhaust gases of the engine 12. As previously discussed, the oxygen sensor 46 generates an oxygen level signal VO used to calculate the measured oxygen level in the exhaust gases. Further, as previously discussed, the measured oxygen level is used to set a condition flag that indicates a the engine 12 is operating in a lean condition or a rich condition. The substep 56 controls the duty cycle of the fuel injectors 22 responsive to the oxygen level.

[0069] Referring to Figure 4C, the substep 56 may include the substeps 60, 62, and 64. The substep 60 calculates a commanded air/fuel ratio AF responsive to the measured oxygen level. Referring to Figure 4D, the sub-

step 60 may include interactively executing the background processing substeps 66-78. Before explaining the substeps 66-78, the variables utilized by the controller 42 in performing these substeps will be explained.

[0070] The variables include:

commanded air/fuel ratio AF = AIR/FUEL_BASE when the controller 42 is initially powered up;

AIR/FUEL_BASE = about 14.6 for conventional internal combustion engines using gasoline;

RS = a rich offset value to increase commanded air/fuel ratio AF when a rich fuelling condition exists;

LS = a lean offset value to decrease commanded air/fuel ratio AF when a lean fuelling condition exists;

RAMP_RATE = ramp rate to modify commanded air/fuel ratio AF when a rich or lean fuelling condition exists.

[0071] While performing the substeps 66-78, the commanded air/fuel ratio AF is increased or decreased using RS, LS, and the RAMP RATE to try to maintain stoichiometric engine operation.

[0072] Referring to Figure 4D, the substeps 66-78 will now be explained. The substep 66 determines whether the measured oxygen level indicates a rich condition. If a rich condition exists, the substep 68 increases the commanded air/fuel ratio AF (AF = AF + RS). As shown in Figures 3D and 3E, the oxygen level signal VO indicates a transition to a rich condition at time T1 which results in the commanded air/fuel ratio AF being increased by RS. Thereafter, the method enters a loop including the substeps 70 and 72. The substep 70 determines whether the measured oxygen level still indicates a rich condition. If a rich condition still exists, the substep 72 further increases the commanded air/fuel ratio AF (AF = AF + RAMP_RATE).

[0073] As shown in Figures 3D and 3E, the oxygen level signal VO after time T1 (and before time T2) still indicates a rich condition which results in the commanded air/fuel ratio AF being increased by RAMP_RATE.

[0074] Referring again to Figure 4D, if the substep 70 or the substep 66 indicates a lean condition, the method advances to the substep 74. The substep 74 modifies the commanded air/fuel ratio AF (AF = AF - LS) to decrease the commanded air/fuel ratio AF. As shown in Figures 3D and 3E, the oxygen level signal V0 indicates a transition to a lean condition at time T=T2 which results in the commanded air/fuel ratio AF being decreased by LS.

[0075] Thereafter, the method enters a loop including the substeps 76 and 78. The substep 76 determines whether the measured oxygen level still indicates a lean condition. If a lean condition still exists, the substep 78 decreases the commanded air/fuel ratio AF (AF = AF - RAMP_RATE) to further decrease the commanded air/fuel ratio AF.

[0076] As shown in Figures 3D and 3E, the oxygen level signal VO after time T2 (and before time T3) still indicates a lean condition which results in the commanded air/fuel ratio AF being decreased by the RAMP_RATE. Finally, if the substep 76 indicates a rich condition, the method advances to the substep 68.

[0077] As shown in Figures 3D and 3E, the method iteratively adjusts the commanded air/fuel ratio AF to try to maintain the engine at stoichiometric, after the fuel pump 28 has been shut off at time T = T0. In particular, the commanded air/fuel ratio AF is progressively decreased to maintain the engine at stoichiometric while the fuel in the fuel rail 24 is being consumed.

[0078] Referring again to Figure 4C, each time the background processing substeps 66-78 modify the commanded air/fuel ratio AF, the method advances to the substep 62.

[0079] The substep 62 calculates a commanded fuelling level W responsive to the measured intake manifold air flow MAF and the commanded air/fuel ratio AF. The fuelling level W may be calculated using the following formula:

$$W = MAF / AF.$$

[0080] The method advances to the substep 64 after the substep 62. The substep 64 selectively increases the duty cycle of the fuel injectors 22 responsive to the commanded fuelling level W to allow the engine 12 to operate cyclically about a predetermined air/fuel ratio. As previously discussed, the predetermined air/fuel ratio is preferably stoichiometric.

[0081] Referring to Figures 3C, 3F, and 3G, after the fuel pump 28 is turned off at time T=T0, the fuel pressure P in fuel rail 24 begins to decrease, and thus the command fuelling level W must be steadily increased to maintain the engine 12 at stoichiometric operation. Thus, the duty cycle of the fuel injectors 22 must also be increased as the fuel pressure P in decreases to keep delivering the required amounts of fuel to the cylinders 18. The duty cycle of each of the fuel injectors 22 may be determined using the following two equations:

$$PW = ((C/AF) * (1/INJS)) + OFFSET;$$

where

PW = commanded pulse width of the fuel injector control signal VFI (seconds);

C = amount of air inducted into a cylinder 18 (lbs.)

AF = commanded air/fuel ratio;

INJS = fuel injector slope (lbs. per second);

OFFSET = pulse width offset due to variable battery voltage (seconds) and,

$$D = S * PW * CF;$$

where

D = duty cycle of the fuel injector control signal VFI;

S = engine speed (revolutions/second)

CF = conversion factor empirically determined responsive to the clock speed of the controller 42.

[0082] As illustrated in Figures 3C, 3F, and 3G, after time T=TO, the average commanded fuelling level W and the average duty cycle of the fuel injector control signal VFI is inversely proportional to the fuel rail pressure P (represented by VP).

[0083] Referring to Figure 4B, the method finally advances to the substep 58 after the substep 56. The substep 58 sequentially ignites fuel from the fuel injectors 22 in the cylinders 18 while the duty cycle of the fuel injectors 22 are being controlled. The substep 58 iteratively ignites the cylinders 18 while the substeps 54 and 56 are also being iteratively performed. In particular, the controller 42 generates an ignition control signal VI for each spark plug 40 responsive to the position of the crankshaft 43 as known by those skilled in the art.

[0084] The duration that the controller 42 performs the step 52 will now be explained in greater detail. Referring to Figures 3E, 3F, 3G, the controller 42 controls engine 12 after the fuel pump 28 has been shut off for an engine shutdown timing interval. The engine shutdown timing interval starts at time T=T0 when the fuel pump 28 is shut off and ends at time T=T4.

[0085] During the engine shutdown timing interval, the fuel injectors 22 supply fuel to the cylinders 18 which is burned therein. Thus, during this timing interval, the measured fuel rail pressure P is decreased as the remaining fuel in the fuel rail 24 is consumed. The end time T=T4 occurs when an engine operational parameter becomes (i) greater than a threshold value or (ii) less than the threshold value.

[0086] The engine operational parameter may comprise (i) the measured fuel pressure P, (ii) the measured oxygen level, (iii) the commanded air/fuel ratio AF, or (iv) the average duty cycle of one or more fuel injectors 22. In particular, time T=T4 occurs when one of the following conditions is met:

measured fuel pressure P < a threshold pressure level;

measured oxygen level > a threshold oxygen level;

commanded air/fuel ratio AF < a threshold air/fuel ratio or

average duty cycle of the fuel injectors 22 is greater than a threshold duty cycle.

[0087] The threshold values including (i) the threshold pressure level, (ii) the threshold oxygen level, (iii) the threshold air/fuel ratio; and (iv) the threshold duty cycle, may be empirically determined by one skilled in the art.

[0088] In particular, the threshold values indicate when the engine 12 is no longer capable of being operated stoichiometric due to insufficient amounts of available fuel in the fuel rail 24.

[0089] For example, referring to Figure 3E, the predetermined threshold parameter AFMIN represents a commanded air/fuel value under which the engine 12 cannot be operated stoichiometric. When the commanded air/fuel value AF is less than AFMIN, the controller 42 stops any further control of the fuel injectors 22 as shown by the average VFI duty cycle being a zero value.

[0090] Further, the controller 42 simultaneously stops any further control of the spark plugs 40 to ignite the fuel in the cylinders 18.

[0091] The method of controlling an engine during engine shutdown to reduce evaporative emissions represents a significant improvement over conventional methods. As shown in Fig. 3C, this invention reduces the fuel pressure in the fuel rail 24 during an engine shutdown timing interval (i.e., time T0-T4) by burning the residual fuel in the fuel rail 24 after the fuel pump 28 has been shut off. As a result, the reduced pressure in the fuel rail 24 reduces the evaporative emissions from the engine 12.

Claims

1. A method for depressurizing a fuel rail (24) in an internal combustion engine (12) during engine shutdown to reduce evaporative emissions, the engine (12)having a fuel pump (28) supplying fuel through the fuel rail (24) to a fuel injector (22), the fuel injector (22) communicating with an engine cylinder (18) **characterised in that** the method comprises the steps of, shutting off the fuel pump (28) and burning off the fuel in the fuel rail (24) after the fuel pump (28) is shut off.

2. A method as claimed in claim 1 wherein during the burning off of the fuel a duty cycle of the fuel injector (22) is controlled to allow the engine to operate generally cyclically about a predetermined air/fuel ratio.

3. A method as claimed in claim 1 or in claim 2 wherein the step of burning off the fuel includes, measuring an oxygen level in exhaust gases of the engine (12),

controlling the duty cycle of the fuel injector (22) responsive to the oxygen level and igniting the fuel from the fuel injector (22) in the cylinder while the duty cycle of the fuel injector (22) is being controlled.

4. A method as claimed in claim 3 wherein the controlling the duty cycle of the fuel injector (22) includes the steps of, calculating a commanded air/fuel ratio responsive to the oxygen level, calculating a commanded fuelling level responsive to a measured intake manifold mass air flow and the commanded air/fuel ratio and selectively increasing the duty cycle of the fuel injector (22) responsive to the commanded fuelling level, after the fuel pump (28) is shut off, to allow the engine (12) to operate cyclically about the predetermined air/fuel ratio.

5. A method as claimed in claim 4 wherein when the oxygen level indicates a lean operating condition the duty cycle of the fuel injector (22) is increased.

6. A method as claimed in any of claims 1 to 5 wherein the burning off of the fuel is stopped responsive to an engine operational parameter and a threshold value.

7. A method for controlling an internal combustion engine (12) during engine shutdown to reduce evaporative emissions, the engine (12) having a fuel pump (28) supplying fuel through a fuel rail to a fuel injector (22), the fuel injector communicating with an engine cylinder (18), **characterised in that** the method includes using a method for depressurizing a fuel rail (24) in an internal combustion engine (28) as claimed in any of claims 1 to 7.

8. A motor vehicle having an engine (12) the engine (12) having a fuel injector (22) selectively supplying fuel to a cylinder of the engine (12), the engine (12) further including a fuel pump (28) selectively supplying fuel through a fuel line (24) to the fuel injector (22) and a controller (42) operatively connected to the fuel injector (22) and the fuel pump **characterised in that** the controller (42) is configured to shut off the fuel pump (28) upon a change of state of an engine control signal and to control a duty cycle of the fuel injector (22), after the fuel pump (28) is shut off, to allow the engine (12) to operate cyclically about a predetermined air/fuel level.

9. A vehicle as claimed in claim 8 wherein the engine (12) has an oxygen sensor (46) operatively connected to the controller (42), the oxygen sensor (46) generating a oxygen level signal indicative of a level of oxygen in exhaust gases of the engine (12), the controller (42) varying the duty cycle of the fuel injector control signal responsive to the oxygen level signal.

10. A engine controller (42) for an engine (12) of the type having an intake manifold (16) with a mass air flow sensor (44) generating a mass air flow signal responsive to an amount of air flow in the intake manifold (16), an exhaust manifold (34) with an oxygen sensor (46) generating an oxygen level signal responsive to an amount of oxygen in exhaust gases in the exhaust manifold (34), and a fuel pump (28) supplying fuel to a fuel injector (22), **characterised in that** the controller (42) is configured and arranged to turn off the fuel pump (28) upon a change of state of an engine control signal, the controller (42) being further configured to calculate a commanded air/fuel ratio responsive to the oxygen level signal, the controller (42) being further configured to calculate a commanded fuelling level responsive to the mass air flow signal and the commanded air/fuel ratio, the controller (42) being further configured to control a duty cycle of the fuel injector (22) (22), after the fuel pump (28) is shut off, to allow the engine (12) to operate cyclically about a predetermined air/fuel ratio.

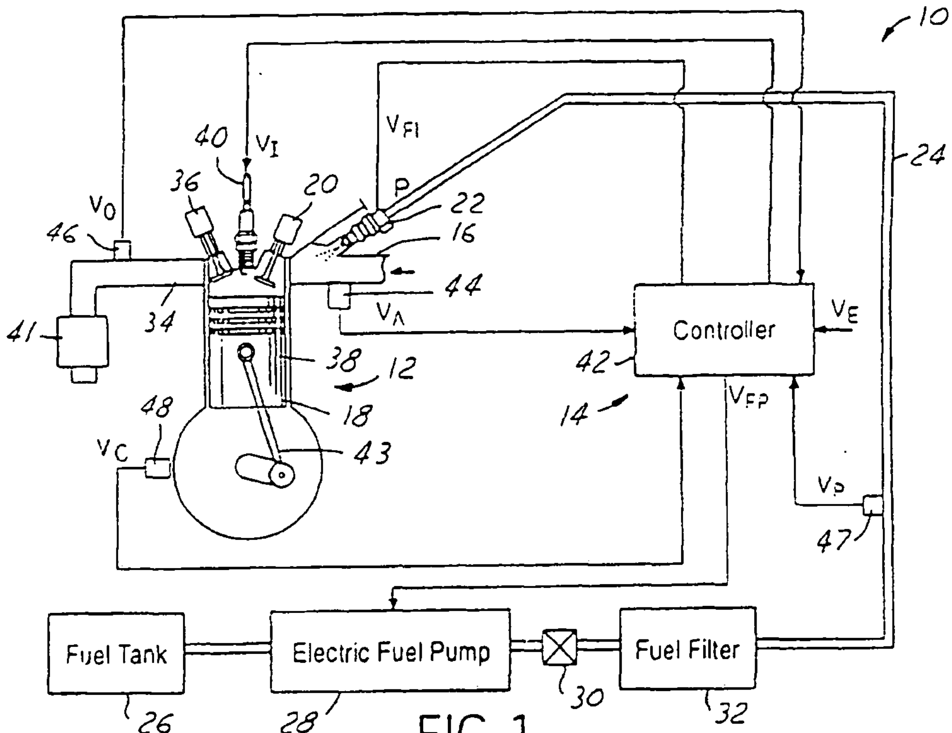

FIG. 1

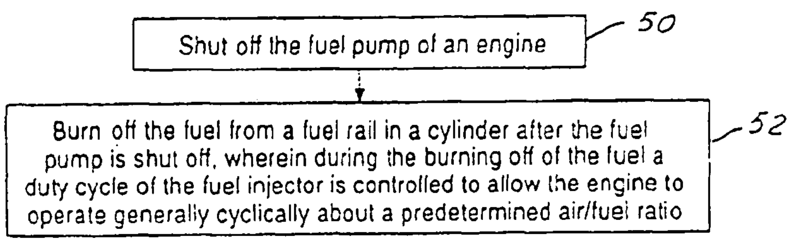

FIG. 4A

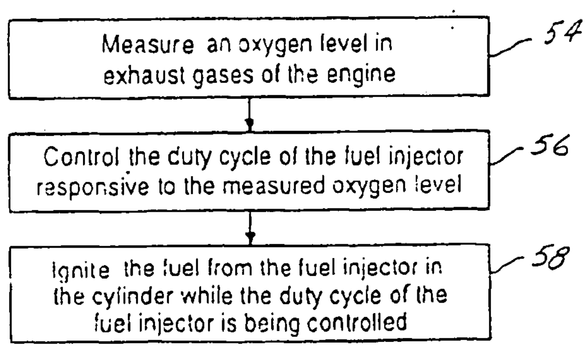

FIG. 4B

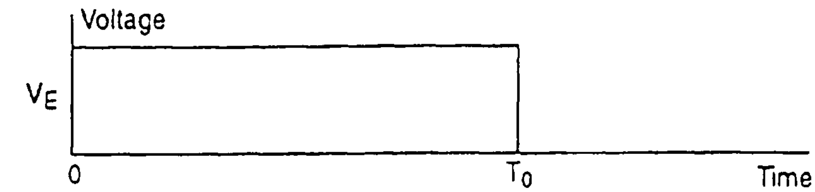

FIG. 2A

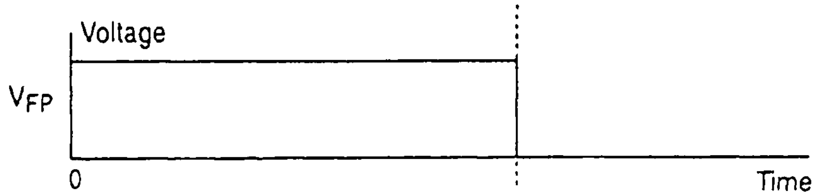

FIG. 2B

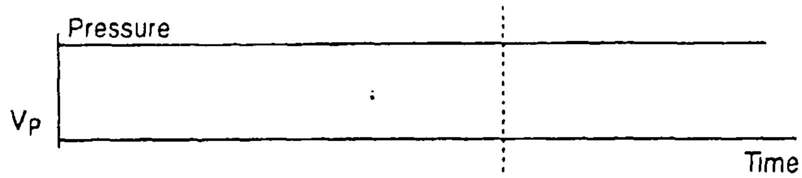

FIG. 2C

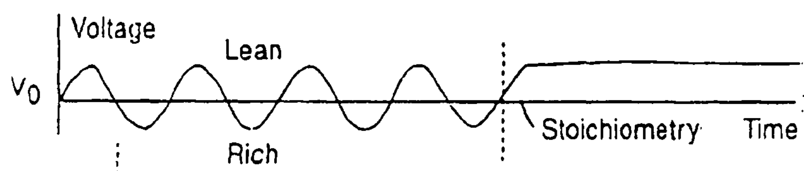

FIG. 2D

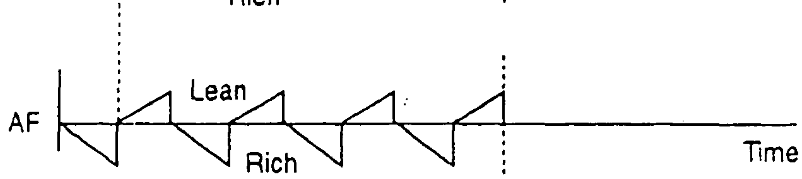

FIG. 2E

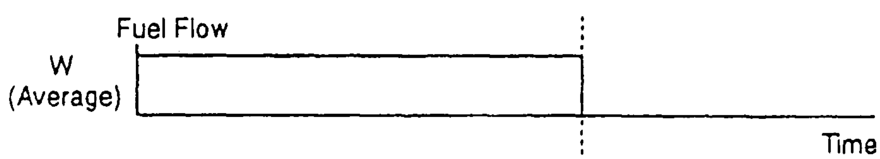

FIG. 2F

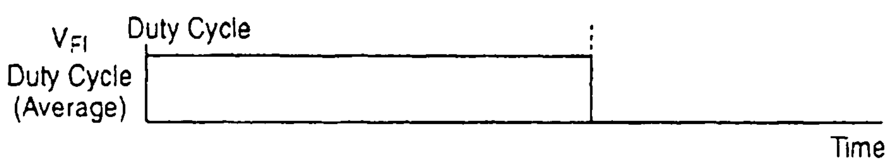

FIG. 2G

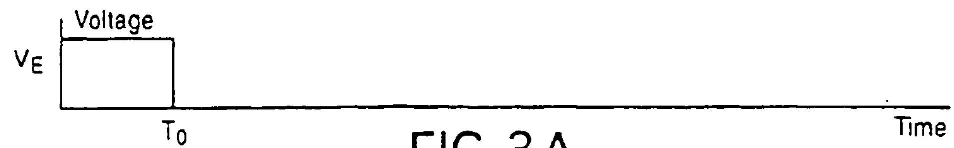

FIG. 3A

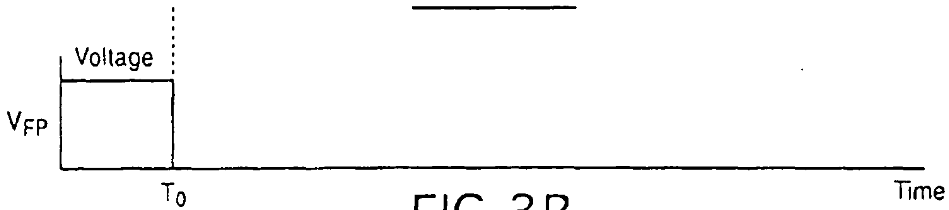

FIG. 3B

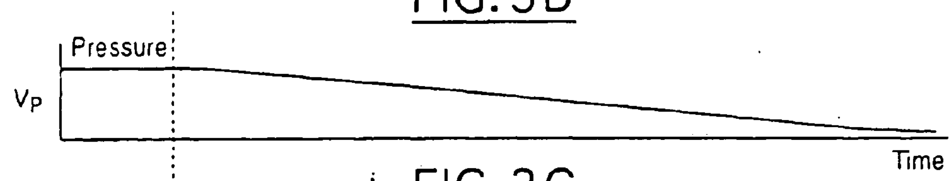

FIG. 3C

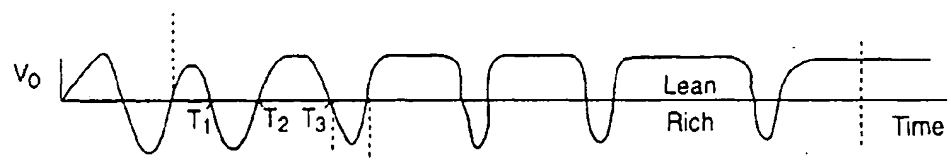

FIG. 3D

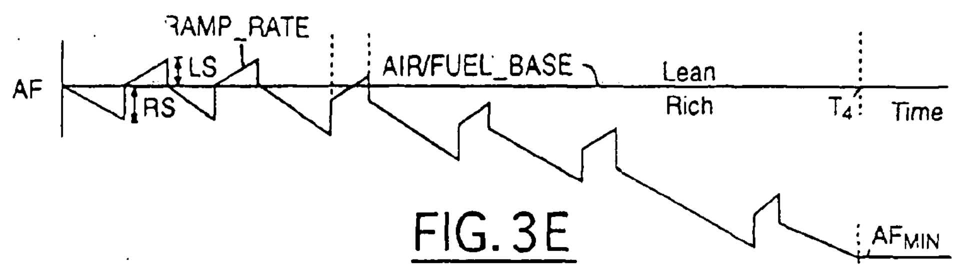

FIG. 3E

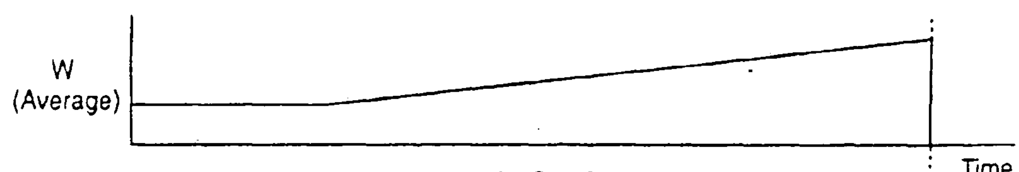

FIG. 3F

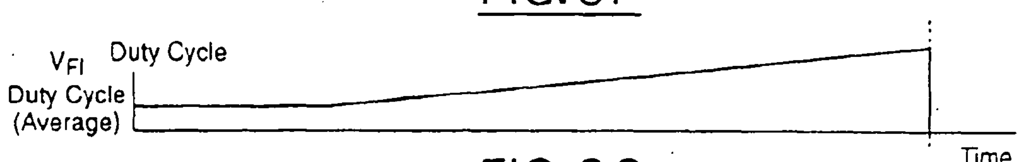

FIG. 3G

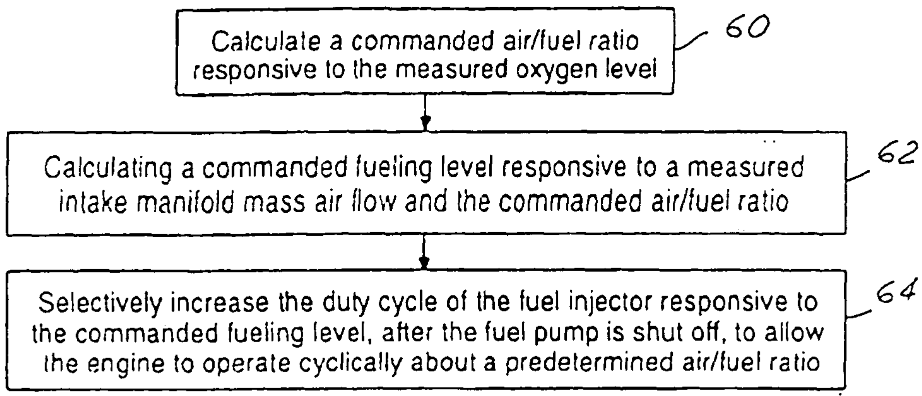
Calculate a commanded air/fuel ratio responsive to the measured oxygen level
60
Calculating a commanded fueling level responsive to a measured intake manifold mass air flow and the commanded air/fuel ratio
62
Selectively increase the duty cycle of the fuel injector responsive to the commanded fueling level, after the fuel pump is shut off, to allow the engine to operate cyclically about a predetermined air/fuel ratio
64

FIG. 4C

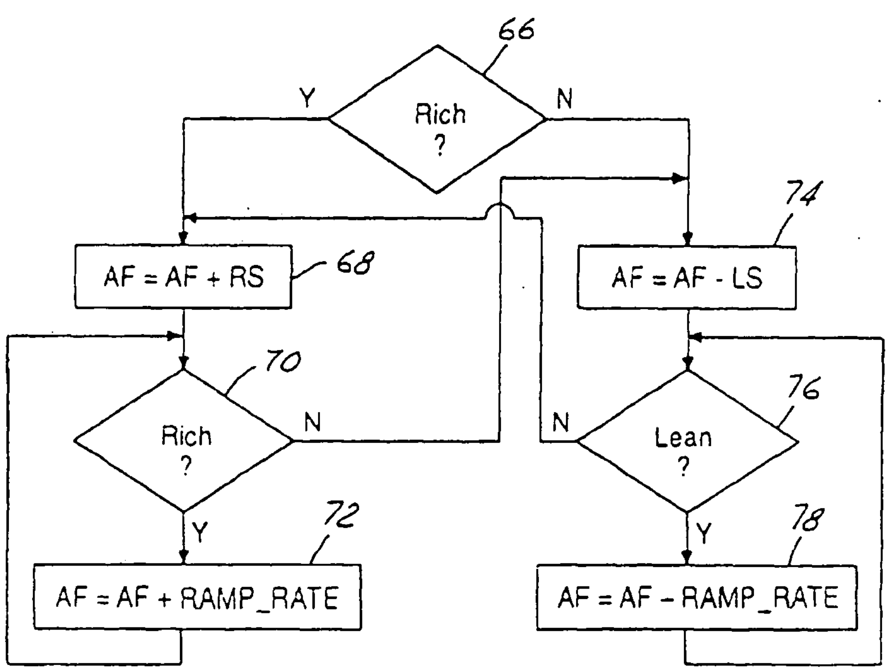
66
Rich ?
Y
N
74
AF = AF + RS
68
AF = AF - LS
70
Rich ?
N
N
Lean ?
76
Y
72
Y
78
AF = AF + RAMP_RATE
AF = AF – RAMP_RATE

FIG. 4D